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DI BÉRENGER'S METHOD APPLICATION IN SOUTHWEST IBERIAN CORK OAK STANDS

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This article analyses the application of the Di Bérenger´s method to uneven-aged cork oak stand (BA > 10m²/ha) located in southwest Spain. The results indicate the difficulty in obtaining the equilibrium curve from Quercus suber *L. species owing to the relationship between growing space and breast-height diameter (DBH) has a high variability. However, in general, it is possible to apply the method to other stands with crown cover areas of less than 100%. The Di Bérenger's curve was elucidated with a power function.*

Key words: cork oak forest; stand structure; uneven-aged stand forest management; crown projection area (CPA); breast-height diameter (DBH).
Parole chiave: foreste di sughera; struttura del popolamento; gestione delle foreste disetanee; area di proiezione della chioma; diametro a petto d'uomo.

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1. INTRODUCTION

The uneven-aged stand structure following an ideal distribution curve allows two departure points, representing two radically different conceptual origins. The most popular is based on LIOCOURT's biological criterion (1898), formulated mathematically in the mid-20th century (MEYER, 1952). This method proposes a distribution of trees that can be developed as an intimate mixture consisting of trees belonging to all or almost all age classes. The second alternative involves obtaining an uneven-aged stand managed by an area distribution standard (HAWLEY & SMITH, 1982; SPIES, 1998; O'HARA, 2002). This case refers to the Di Bérenger's method (DI BÉRENGER, 1871), which is very well known not only to Spanish authors (OLAZABAL, 1883; MACKAY, 1949, PITA, 1971; SERRADA, 2002) as HAWLEY & SMITH (1982), in American forestry literature, also include it. However, these influential American authors do not cite Di Bérenger and designate the Di Bérenger approach as "selection method", specifying that in this method the trees to be cut are the oldest ones in a stand at repeated intervals throughout the cutting cycle.

The Di Bérenger's method analyses the issue of uneven-aged stand management, accepting that a balanced uneven-aged stand can be defined in reference to the amount of growing space taken up by a tree (GOODBURN & LORIMER, 1999). This amount of space is often represented by the horizontal crown area or an area obtained by mathematical area assignment procedures (VIEIRA, 1950; ASSMAN & GARDINER, 1970; HELMS, 1998) and also responds to the concept of occupation area in relation to tree size (CUADROS, 1996). However, HAWLEY & SMITH (1982) affirm that the crown projection area is not totally occupied by smaller trees and that the open areas due to the removal of the oldest trees are partially taken up by the expansion of the crowns of the nearest groups of trees, so that in the latter case they would actually be carrying out improvement cuttings. Once it is determined that every hectare equally includes all size classes into which the stand may be structured (O'HARA, 1996), and that each class has a predetermined number of

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trees depending on the amount of space occupied by each tree, it is possible to obtain the distribution curve per hectare of trees by size classes. In brief, a normal stand is defined by the number of trees of each size class located in a hectare, coinciding with HAWLEY & SMITH (1982) in assigning an equal area to each size class. The uneven-aged stand would consist of a set of balanced structures where the silvicultural treatment units are no longer isolated trees, but groups of even-aged trees (AUNÓS, 2005).

Di Bérenger's method assumes that there is no difference between the current, average and yearly growth rates (OLAZABAL, 1883). These assumptions oblige us to admit that the recruitment period from one diameter class to the next highest is a constant (MACKAY, 1949). The crown projection of each diameter class occupies an equal area, in such a way that we may imagine as many equal areas as there are diameter classes (PITA, 1971). This idea is endorsed by the Society of American Foresters (1994 cited in GOODBURN & LORIMER, 1999), since the association defines a balanced uneven-aged stand as one in which each group of trees belonging to a size class takes up an equal area.

The Di Bérenger's approach[1] is backed by authors who consider uneven-aged stands closer to natural processes (MAYR, 1907; SHÜTZ, 1997; O'HARA, 2002), although they give rise to more sensitive structures needing frequent silvicultural treatments (LANIER, 1986). Documentary rigour calls for the viewpoint of other authors such as CIANCIO & NOCENTINI (1994). These authors, in line with the idea expressed by GURNAUD (1890), agree that the bases of a natural silviculture should be conceived as an open project applied to small forestry areas, groups of trees and even individual trees without preconceived forestry management standards. This system regards the forest as an entity with rights. From another viewpoint, the irregular stand structure, in terms of size classes, following the Di Bérenger´s method, is easier to understand and manage (MACKAY, 1949). Moreover, its use achieves sustainable yield in smaller stands (LANIER, 1986; YOUNG & GIESE, 2003).

During the historical development of management methods for uneven-aged stands, several Spanish authors referenced the model proposed by Di Bérenger, sometimes implicitly rather than explicitly, in their proposals. Prior to analysing its practical application, it seems appropriate to review the state of the question.

JORDANA (1872) recommended reforestations determining the number of saplings needed for new growth to be uniform, prescribing cutting down decrepit trees during the transitory rotation, ensuring the replacement of cut trees.

The first Spanish author to describe the method in detail, and whose work served as the basis for successive publications, was OLAZÁBAL, in the first ever Forest Management manual published in Spain: Ordenación y Valoración de Montes [Forest Appraisal and Management] (1883).

However, it should be emphasised that the notion of an uneven-aged stand distributed in regular patches was present in the mind of the early Spanish foresters from the outset, since it presented a normal stand more readily applicable and controllable. XIMENEZ DE EMBÚN (1951) posits a definition of uneven-aged stands which fits perfectly with the premises of the Di Bérenger's method: *Now let us imagine a forest where each area covered by trees one, two, three…years old was exactly equal to what those ages would occupy in an evenly structured forest (…), but suppose that instead of being grouped in different places, trees of all ages are here and all of them intimately mixed across the whole forest area.*

The second Spanish treatise on forest management was written in two volumes by MACKAY (1944, 1949). This handbook references Di Bérenger, while basing its text on OLAZÁBAL (1883), affirming that: *in terms of organising process, it is reduced to comparisons between numbers of trees classified by diameters; volumes do not count; when indicating the upper limit to*

[1] In 1893 Hufnagl (MACKAY, 1949) made a modification to the Di Bérenger's method, which is not mentioned in this study, considering that it may be implemented effectively in woodland for timber production.

each class it acknowledges, albeit implicitly, the felling of trees by size criteria.

Among European authors, ASSMANN & GARDINER (1970) believe that one crucial aspect when the unit of silvicultural treatment is the individual tree is the definition of the amount of growing space taken up by a tree and the lateral competition supported by this tree in expanding its growing space. These authors also note that the area potentially available for a tree is defined by its horizontal crown projection plus the area corresponding to the fraction not occupied. This appraisal is critical when dealing with stands without tangential crowns and where canopy cover is less than a hundred percent.

One view of uneven-aged stands close to the approach discussed above is presented by PITA (1971). This author believes that the irregular stand structure is due to a dynamic balance between felling and regeneration whereby the mature tree, which occupies an important area of land, is succeeded by an abundant new growth of saplings, where the struggle to survive finally leaves a single tree, beginning the cycle over again. Pita makes implicit reference to the area occupied by the individual tree and reflects the distribution concept adopted by Di Bérenger by placing a single tree at the top of the distribution pyramid by diameter classes, and the horizontal crown area occupied by each diameter class will be calculated by the area occupied by this tree from the upper maximum diameter limit.

Criticism of the assumptions of the method comes from SERRADA (2002), who estimated that the method, *in theory*, suffers the disadvantage of supposing a full canopy cover (100%) over the life of the stand, as well as being based on the estimated modular values of crown projection which may not be constant, depending on the density and treatment given to the stand. Nevertherless, SERRADA (2002) makes an exception that allows the application of Di Bérenger's model to cork oak woodlands in a dense stand model, stating that it may be used in cases where the normal density is incomplete and the site quality has no major spatial variations. This exception allows the use of the method in the dense forest model proposed, which entails a canopy cover of less than one hundred percent in stands with a normal canopy cover.

The method was developed in Spain over the last century. The first forests that were managed by Selection System obtained the normal distribution curve by the Di Bérenger's method, the only procedure documented in the Spanish literature (OLAZABAL, 1883; MACKAY, 1949).

Between 1960 and 1980, several pine forests in Valladolid were managed by the selection system. This is the case, among others, of the "El Bosque" and "Llano de San Marugán" woodlands in 1966 and "Ontorio", "Antequera" and "Esparragal" in 1974 (FINAT *et al*., 2000). This author notes that the selection system method is especially suitable in pine forest management for pine-nut harvesting and recreational use. These projects illustrate the management of uneven-aged stands in Spain. They are of particular interest because, theoretically, they apply the theories of Liocourt but obtain the balanced distribution curve by means of the Di Bérenger's criterion.

Recently, the research has again approached aspects related with the Di Bérenger's method. Different authors, mostly in the Anglo-Saxon area, have obtained ratios between normal diameter and crown projection or crown width in broadleaves and conifers (KRAJICEK, 1961; CURTIN, 1964; TABBUSH & WHITE, 1988; SMITH & FARRAR, 1992).

Why study its application in cork oak forests?

The presence of numerous minor cork oak forests and the fact that uneven-aged stands ensure a balance among age classes in small areas encourage the notion of the irregular structure organised by series of trees as a structure able to produce constant cork-producing areas (MACKAY, 1949). This irregular structure by series of trees is close to the stand structure proposed by DI BÉRENGER (1871).

VIEIRA (1950), implicitly indicates this method when after praising the irregular structure as a guarantee of the persistence and renewal of cork oak stands. He presents an example developed using the Di Bérenger's method.

The aim of this work is the application of the Di Bérenger's method with a species such as cork oak. This species has a series of features that can facilitate and even make its use appropriate, such as:

– it is light-demanding species, although in need of protection in the early stages;
– the seeds have a tendency to remain in the vicinity of the seed tree (JORDANA R., 1872; TORRES, 1995);
– regeneration is concentrated in the periphery of the crown, even around the older trees (NEGER, 1908);
– cork oak stands allow tree by tree mixtures and cluster mixtures, the latter being more common;
– the canopy cover is not complete, but this is not a problem in this method because the normal density in cork oak stand is incomplete (SERRADA, 2002).

2. MATERIAL AND METHODS

2.1. Study zone description

The study area is located in Management Area A within the Jerez forests. This is a cork oak forest in a dense stand model (BA > 10m^2/ha), with mixed stands of cork oak (*Quercus suber* L.) and Lusitania oak (*Quercus canariensis* W.) with the presence of wild olive trees (*Olea europaea* var. *sylvestris* Brot.). Cork oak is the main species from the silvicultural point of view. The mixture does not usually occur tree by tree but in clusters, small groups and clumps. The courtship flora is rich in species, including laurel forest species such as *Rhododendron ponticum* and *Laurus nobilis*, among others.

According to SERRADA (2002), it is possible to apply the method to these cork oak stands due to the normal canopy cover is incomplete and the site quality is homogeneous.

2.2. Inventory carried out for method application in Forest Management Area A in Jerez (2003)

Following the general inventory of the Jerez forests (MARIN-PAGEO *et al.*, 2000), the practical application of the Di Bérenger's method called for an additional inventory (ALEJANO *et al.*, 2003), carried out to provide more information on the sample trees by diameter class, including their areas of influence or modular values.

The general inventory consisted of a systematic sampling with a sampling grid of 200 metres per side and an 18 metre plot radius. The result of this design is the measurement of 93 plots. The 5 tally trees closest to the centre without tangency of crowns are measured. In total, 237 trees were considered.

Influence area is defined as the physical area available for a tree (HELMS, 1998). This area is delimited by competition with adjacent trees (KRAJICEK, 1961; GARDINER & ASSMANN, 1970).

Another aspect to consider when applying this method is the crown projection shape and hence the area of influence, in English terminology, the *area potentially available*. In this paper we shall define the area as circular. Studies carried out on other species, although in conifers, have considered this the ideal shape (KRAJICEK, 1961; SMITH & FARRAR, 1992). In principle, there is no reason other than those described by previous authors. It was found that the orientation factor, directly related with exposure to excessive sunlight as well as low temperatures, had no effect and so the existence of privileged directions was not considered. As a result, it is possible to reject the ellipsoidal shape. Moreover, in species that may be subject to cultural treatments, the crown form can be trained toward a particular shape. The crown width can also be measured through three diameters at 60º intervals, choosing the first at random (CURTIN, 1964).

This work examines the DBH as a variable, relating it with crown area, directly connected with the occupancy area, which will be considered circular (KRAJICEK, 1961; SMITH y FARRAR, 1992; TORRES, 1995).

The following variables and features were measured:

– Nº of saplings (DBH <10 cm and height < 1.3 m).
– Distance from saplings to seed tree: Determination of the area of influence or occupation.
– Breast height under cork diameter (DBH), also known as normal diameter.

- Tree crown width was taken as the mean of two perpendicular diameters; the first diameter was taken at random.
- Spatial distribution of stand structure and measurement *in situ* of the spacing distance between trees in the stand.

Data analysis using regression must provide the following information needed to apply the Di Bérenger's criterion:

- Relation between average crown diameter and normal diameter in order to determine the average tree crown area of each diameter class.
- Influence area of the average tree from each diameter class.
- Relation between the influence area and crown area of the average tree of each diameter class.

3. Results

The Di Bérenger's curve, which will be the forest management model indicating the distribution of trees per hectare and diameter class, is to be determined on Management Area A.

The area corresponding to each diameter class per hectare is the result of the quotient between one hectare and the number of diameter classes considered. As the area of influence or occupation of the average tree from each class is recorded in the inventory, the number of trees per diameter class included in each hectare is calculated.

3.1. Relation between breast-height diameter and crown projection area

Power, exponential, logarithmic, linear, and polynomial regressions were analysed. Power regression provided the best fit, with R^2 values of 0.4838, which will be the curve used in the subsequent Di Bérenger's method analysis. The curves of the functions analysed are reflected in Figure 1 and Figure 2, where CPA is the horizontal crown projection area and DBH is the breast-height diameter.

3.1.1. Analysis of the relation between average crown area and influence area

Regarding sapling distribution, the specific inventory carried out for Di Bérenger's method implementation indicates the presence of groups of sapling on the crown projection periphery.

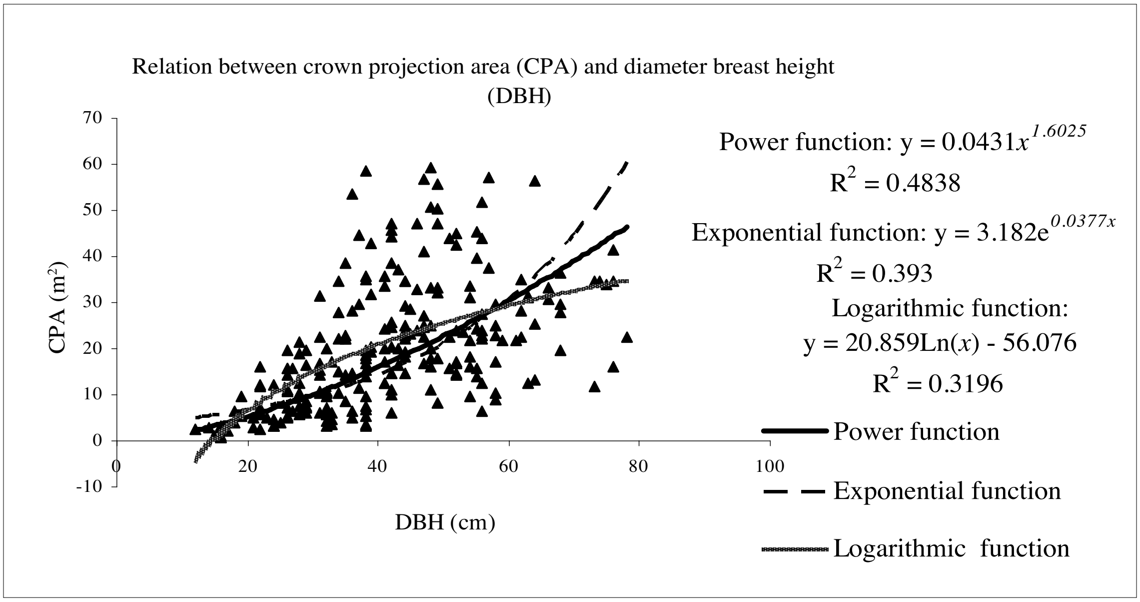

Figure 1 – Relation between breast-height diameter and crown projection area.

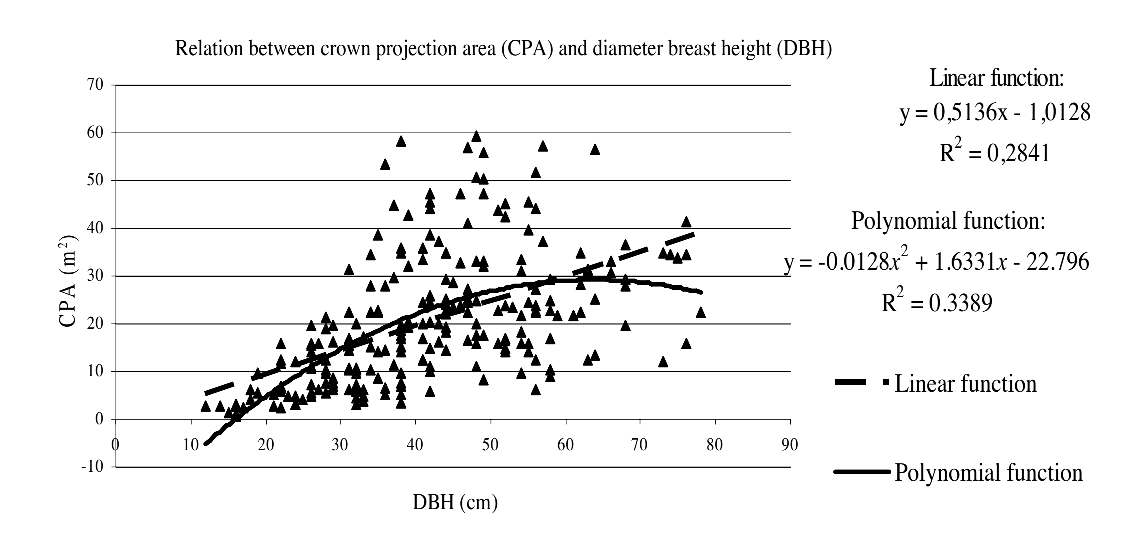

Figure 2 – Relation between breast-height diameter and crown projection area: linear and polynomial functions.

The results from the plots in the specific inventory for this case (ALEJANO *et al.*, 2003) indicate that in general the influence or occupation area (influence of regeneration) coincides with the crown projection area (CPA). Differences are found only in cases where the slope has caused acorn displacement, described by other authors (VIEIRA, 1950; TORRES, 1995).

3.1.2. Spatial distribution of the structure

The forest is organised in clumps and occasionally groups, as may be deduced by observing the plots in the inventory carried out in 2000 in Management Area A (MARIN-PAGEO *et al.*, 2000). This structure conceptually facilitates, *a priori*, the implementation of Di Bérenger's method.

3.1.3. Calculation of growing space for the average tree from each diameter class (class centre)

This calculation is based on the potential equation obtained by regression analysis being the best fitting curve. The shape of the growing area was considered to be circular. Table 1 is obtained by including class centre values in the function:

$$y = 0.0431 \cdot x^{1.6025}$$

Table 1 – Growing space for average tree of each diameter class.

Diameter function class centre (cm)	Crown or occupation area by $y = 0.0431 \cdot x^{1.6025}$ *(x is breast-height diameter in cm)* (m^2)
15	3.3
25	7.5
35	12.9
45	19.2
55	26.5
65	34.6
75	43.6

3.2. *Balanced distribution curve according to Di Bérenger's method*

The regulated (normal) forest is based on the balanced distribution curve bases as determined by Di Bérenger, proceeding in the following steps:

- Seven diameter classes are considered, measured in centimetres in the stand inventoried: 10-19; 20-29; 30-39; 40-49; 50-59; 60-69 and 70-79 cm.
- The total growing space per hectare is reduced to the canopy cover considered normal according to species, site and forest management.
- Accepting the assumption that each diameter

class must occupy the same area, the canopy cover to diameter class ratio is calculated.
– The number of trees that must be present in each diameter class is calculated in relation to the growing space occupied by each sample tree.
– The ideal curve which serves as the forest regulation standard is plotted.

The balanced diameter distribution was estimated with the following data:
– Canopy cover: 60%.
– Number of diameter classes considered: 7.
– Area occupied by each diameter class in normal forest:

$$\frac{6000\,m^2}{7} = 857\,m^2$$

– Number of trees in each diameter class shown in the Table 2.

Table 2 – Di Bérenger balanced distributed curve: number of trees per diameter class.

Diameter class centre (cm)	Individual occupation area (m^2)	N° of trees per diameter class
15	3.3	260
25	7.5	114
35	12.9	66
45	19.2	45
55	26.5	32
65	34.6	25
75	43.6	20

The individual growing space was calculated from the selected balanced distribution curve; the power function is:

$$y = 0.0431 \cdot x^{1.6025}$$

The Di Bérenger curve was obtained from the Table 2 data by regression analysis, as shown in Figure 3.

The best fit was presented by the power function:

$$y = 19407 \cdot x^{-1.5953}$$

with R^2 =0.9999, where "y" is the number of trees per hectare and x is the diameter class centre in centimetres.

Figure 4 shows the function and curve with best fit (R = 0.9999) selected to represent the Di Bérenger model. In this case, the power function is:

$$y = 19407 \cdot x^{-1.5953}$$

4. DISCUSSION AND CONCLUSION

The best fit function to obtain the Di Bérenger's curve in the case studied is the power function with R^2 = 0.9999, although the exponential function obtains R^2 = 0.9455. This result coincides with that reported by SHIMANO (2000) who achieved the best fit with power functions to describe DBH-class distribution

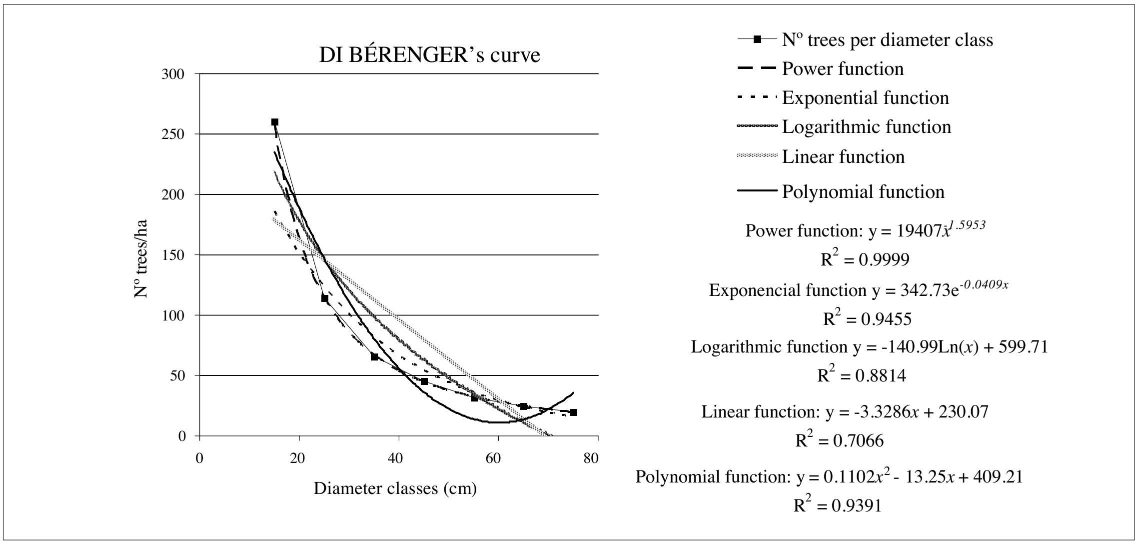

Figure 3 – Di Bérenger's curve.

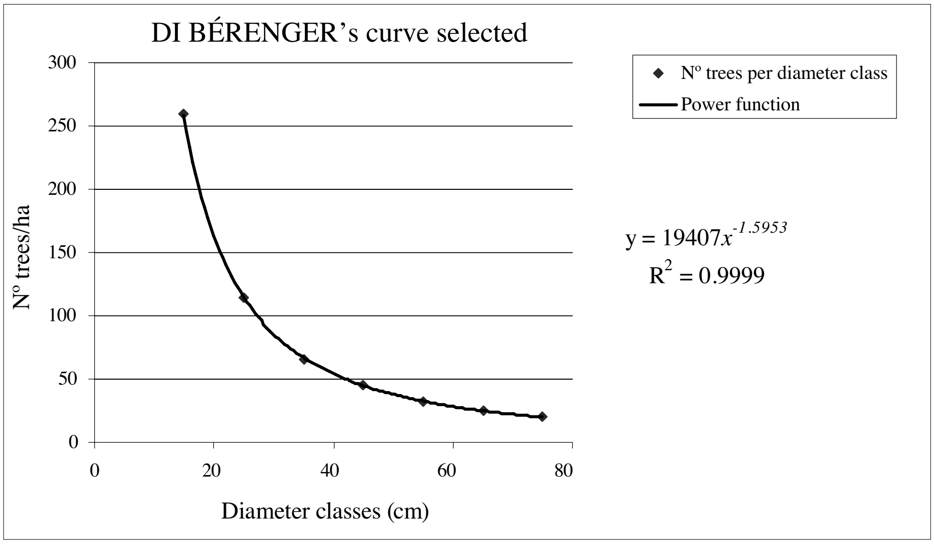

Figure 4 – Di Bérenger's curve selected.

in *Fagus crenata* forest with data gathered by means of the distribution procedure observed.

The best fit for the CPA/DBH relation obtained for *Quercus suber* L. in the Jerez forest Management Area A by regression corresponds to a power function compared with the expected result of the exponential. This paper presents a low fit (0.4838) in the CPA/DBH distribution curve, especially when compared with results obtained by the same method from trees without competition, by FARRAR & SMITH (1992) for *Pinus taeda* L., *Pinus echinata* Mill. and *Pinus palustris* Mill., with fits above 0.9 and smaller sample sizes. TABBUSH & WHITE (1988), in a non-competitive situation, obtained for *Picea sitchensis* (Bong.) Carr. an r=0.93 with a sample size of 72 individuals.

From Shimano's work, it appears that conifers respond to the best fit model, although it cannot be ignored that the studies were conducted on open-grown trees selected for their good characteristics in terms of crown size and shape. The analysis was carried out on samples between 73 and 157 individuals (SMITH & and FARRAR, 1992; TABBUSH & WHITE, 1988), and it can be seen that these sample sizes are lower than in the present study (237 individuals).

It is important to note that the species in all these works, mostly in conifers, provide less variability in their appearance and crown shape than *Quercus suber* L. which is characterised by polymorphism (VIEIRA, 1950) and irregularities in appearance when growing in dense forest (MONTERO & CAÑELLAS, 2003).

The well-known refusal of the property to cut down trees in production shows the non-applicability of a rigorous model on the basis of trees selected for their good shape and measurement, since no correlation can be established between appearance and cork production, so a standard under these circumstances those would be unfeasible.

Of the works reviewed, the only one to apply the Di Bérenger's method and specifically in cork oak, is VIEIRA (1950). He describes the case of a hectare of inventoried cork oak forest.

This is typical Portuguese "montado" forest, with a total of 103 trees. The individual occupation area of each breast-height girth is calculated. Vieira estimates the area of occupancy for each diameter class at 966 m^2 and this value differs little from that presented in this study, which amounts to 857m^2. Vieira considers 6 size classes instead of the 7 analysed in this research, which may explain the difference in occupancy area by size class described (Table 3).

It was determined that to achieve a well illuminated stand (LAGUNA, 1883) the total oc-

Table 3 – Calculation of individual occupation area of a Portuguese "montado" stand (VIEIRA, 1950).

GBH (Girth breast height) (m)	Nº trees (m²)	Individual occupation area (m²)	Total occupation area
0.80	12	27.56	330.72
1.00	20	42.82	856.40
1.20	45	58.08	2.613.60
1.40	26	80.97	2.105.22

cupancy area should not exceed 5800 m² per hectare, thus avoiding the tangency of crowns and leaving the trees free of competition.

Another aspect which has been looked into by different authors is the stand density, and most of them have collected data on trees without competition. This factor must be recognised and uniform in the sample. In fact, the initial failure to relate crown diameters with stem diameters arose from the presence of competition among trees.

The low correlation CPA/DBH obtained in this work may be attributed to the competition factor, unlike those listed in the cited works. In this study, although the forest is understocked by 60%, trees suffer from internal competition within groups of trees.

The relationship between average crown projection and normal diameter (DBH) allows calculation of an ideal distribution curve according to the Di Bérenger's method. However, in the present case we find it difficult to establish a constant relationship between incidence areas and normal diameters (correlation 0.4838), so it is hard to derive a "balanced curve" with a constant number of trees in each diameter class.

Its application in smaller cork oak stands with a uniform site is unknown. In this case, in future studies it would be interesting to propose the Di Bérenger curve as reference, refraining from a too-rigorous application while the results of future research remain unknown.

The initial structure is an important deciding factor, since it is impossible to compensate the owner for cutting trees in production. Consequently, the stand must have an irregular structure or exhibit this tendency.

RIASSUNTO

Applicazione del metodo di Di Bérenger ai popolamenti di sughera della Spagna sud-occidentale

L'articolo analizza l'applicazione del metodo di Di Bérenger ai popolamenti di sughera della Spagna sud-occidentale (AB > 10 m²/ha). I risultati indicano la difficoltà a ottenere la curva di equilibrio dalle specie di *Quercus suber* L. poichè la relazione tra area di crescita e diametro a petto d'uomo ha un'alta variabilità. Comunque, in generale, è possibile applicare il metodo ad altri popolamenti con area di copertura delle chiome inferiore al 100%. La curva di Di Bérenger è stata spiegata come una funzione potenza.

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